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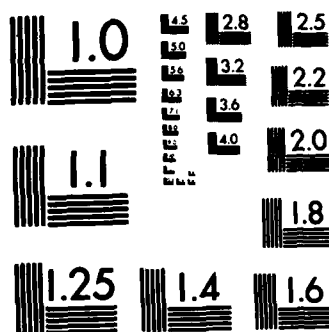
GENERATING MONITORING AND CONTROLLING PETROLEUM  
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**Chemical Characterization and  
Toxicologic Evaluation of  
Airborne Mixtures**

**Generating, Monitoring and  
Controlling Petroleum Aerosols  
for Inhalation Chamber Studies**

TASK SUMMARY REPORT

R. W. Holmberg  
J. H. Moneyhun  
T. M. Gayle

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U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND  
Fort Detrick, Frederick, MD 21701

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Project Officer: James C. Eaton

Health Effects Research Division  
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20. toxicology experiment for the past two years. Aerosol concentrations from 0.25 to 20 mg/L (routinely to 6 mg/L) have been developed for periods up to six hours. The generators, the monitoring system, and the spent aerosol removal system have also been found effective for less volatile petroleum based obscurants such as Fog Oil. This report emphasizes the hardware and electronic control system; the characterization of the aerosol with respect to both its physical and chemical properties (Ref. 6) and a discussion of the toxicology (Ref. 3) have been presented elsewhere.

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AD ORNL/TM-8903

## Chemical Characterization and Toxicologic Evaluation of Airborne Mixtures

## GENERATING, MONITORING AND CONTROLLING PETROLEUM AEROSOLS FOR INHALATION CHAMBER STUDIES

## TASK SUMMARY REPORT

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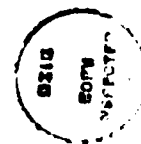
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## TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES . . . . .	2
LIST OF TABLES . . . . .	3
INTRODUCTION . . . . .	5
GENERATOR DESIGN . . . . .	6
CHAMBER DESIGN AND MODIFICATION . . . . .	9
MONITORING AND CONTROL . . . . .	17
TEMPERATURE CONTROL OF AEROSOL GENERATOR . . . . .	25
SAFETY CONTROL SYSTEM . . . . .	25
FOG OIL . . . . .	31
LITERATURE CITED . . . . .	34
PERSONNEL . . . . .	36
PUBLICATIONS . . . . .	37
DISTRIBUTION LIST . . . . .	38

# LIST OF FIGURES

	<u>Page</u>
1. Diesel Fuel Aerosol Generator . . . . .	7
2. Metering Pump-Diesel Fuel Aerosol Generating System . . . .	8
3. Exposure System Schematic . . . . .	10
4. Diesel Fuel Aerosol Entering Exposure Chamber Without Laminarizing Screens . . . . .	11
5. Laminarizing Screens and Dispersing Cone . . . . .	12
6. Inhalation Chamber Filling with DF2 Aerosol-Laminarizing Screens in Place . . . . .	13
7. Inhalation Chamber Emptying-Laminarizing Screens in Place .	14
8. Multisensor Response Showing Homogeneity of DF2 Aerosol . .	16
9. Filling and Emptying Dynamics of Inhalation Chamber . . . .	18
10. LED-Phototransistor Aerosol Sensor . . . . .	20
11. Basic Aerosol Concentration Measuring System . . . . .	21
12. Schematic of Amplifier-Integrator Readout Module . . . . .	22
13. Readout Module with Case and Probe . . . . .	23
14. Probe Assembly Detail . . . . .	24
15. Particle Sensor Response vs. Diesel Oil Aerosol Concentration . . . . .	26
16. Temperature Control Network for One Aerosol Generator . . .	27
17. Safety Shutdown Control . . . . .	28
18. Relay System for Alarm and Shutdown . . . . .	30
19. Particle Sensor Responses to Fog Oil Aerosols Concentration = 0.5 mg/L . . . . .	32
20. Particle Sensor Responses to Fog Oil Aerosols Concentration = 5 mg/L . . . . .	33

## LIST OF TABLES

	<u>Page</u>
1. Spatial Homogeneity Summary for Chamber with Laminarizing Screens . . . . .	15

## INTRODUCTION

Two Army obscurant systems are based on the use of petroleum aerosols. One, designated by the acronym VEES, for Vehicle Engine Exhaust Smoke System, uses DF2 grade diesel fuel, delivered in aerosol form, from a diesel powered vehicle such as a military tank.<sup>(1)</sup> In this system the same oil that powers the tank is pumped into the hot exhaust manifold directly after the diesel engine where it immediately vaporizes. The vapors are carried through the exhaust system and forcibly ejected into the air, along with the normal exhaust gases. The oil vapors contacting the cooler air condense to form a dense aerosol that is used for screening purposes. The other system uses "Fog Oil", a less volatile petroleum fraction similar in physical properties to 10W lubricating oil. It is deployed in portable generators such as the M3A3<sup>(2)</sup>. The aerosol generation is similarly an evaporation-condensation process. The Fog Oil is introduced into a pulsed combustor, is vaporized, and is condensed as aerosol particles when expelled into the cooler air.

Both of these systems are designed to obscure large areas. Typically they use oil at a rate of one gallon per minute, most of which condenses to form the obscurant aerosol. The size of such equipment and the difficulties attendant to handling and disposing of such large volumes of smoke precluded their use in a toxicology laboratory environment. This report then describes a generator and exposure system for rodents which operates on a much reduced scale (oil flow rates of a few milliliters per minute) yet produces smoke which has many of the properties of that produced in the field. In this report the generator and the exposure facility as they apply to the diesel fuel aerosol are described. The generator has been tested and found to operate satisfactorily on Fog Oil in laboratory pilot studies, but operating experience in large scale inhalation exposures has yet to be obtained. Its operation with Fog Oil will be discussed briefly later.

The predominant constituent of a smoke cloud from the VEES system is the diesel fuel in aerosol form. The noxious constituents of normal diesel exhaust, typically carbon monoxide, nitrogen oxides, unburned hydrocarbons and the black sooty particles, form but a minor fraction of the aerosol. For example, particulates in normal diesel exhaust emissions are of the order of milligrams per cubic meter while the aerosol levels that we are concerned with are of the order of grams per cubic meter. In the toxicology study that is now underway<sup>(3)</sup>, these constituents of normal diesel exhaust emissions are not introduced into the system. To do so, for example, adding a small diesel engine to the exposure system, would have posed engineering problems that would have strained the resources and timing of the investigation without necessarily gaining in relevancy.

The generator, described below in detail, does have provisions for introducing the constituents of normal diesel exhausts and, in particular, studying the chemical effects of the combustion gases on the diesel oil. Normally a diesel engine operates with a stoichiometric

excess of air to fuel by approximately a factor of two. In the VEES system, the diesel oil is vaporized at high temperature in an atmosphere of these combustion products: nitrogen, carbon dioxide, water vapor, and unconsumed oxygen. It is the oxygen that most likely can react with the oil to produce compounds not present in the pure diesel oil aerosol.

#### GENERATOR DESIGN

A detailed diagram of the generator is shown as Figure 1. As mentioned above, it was designed to be able to simulate the processes that occur in the much larger VEES system using diesel oil. A one kilowatt Vycor immersion heater is inserted in one end of a one meter long, one inch diameter stainless steel tube. This region then simulates the manifold of the diesel engine. The temperature is controlled with a thermocouple and its associated controller. The petroleum oil is injected through a small tube located near the tip of the heater. At the operating temperature (typically 600°C), it flash evaporates and is carried down the remainder of the generator tube.

This second region, about 2/3 of the length of the tube, represents the exhaust system of the diesel vehicle. It was made sufficiently long so that the oil vapors and exhaust gases could cool and exit at temperatures approximating those in the large scale vehicle. To prevent excessive cooling a glass fiber insulated tape heater is wound externally around the tube in this region. This heater is also monitored with a thermocouple so that the temperature of the exiting gases and vapors can be controlled. Typically this temperature is maintained at 350°C.

The aerosol concentration is controlled by the rate of air flow through the exposure system and by the rate at which oil is delivered into the generator. Some losses of aerosol particles do occur before they reach the chamber and, with diesel oil, losses by evaporation of its more volatile constituents can occur. Oil is metered into the generator with a system shown as Figure 2. A metering pump, whose flow rate is controlled by means of a micrometer adjustment, supplies oil to the generator at a constant rate. To protect the pump and to prevent plugging of the delivery system, the diesel oil passes through a small filter (Balston Filter Products Cat. #9933-05 grade DQ) before it enters the pump. The pump is primed and gas bubbles are removed from the line without disassembly of the system. The three way valve (Figure 2) is turned to the siphon position and suction is applied until bubble free oil flows through the filter and pump. A pressure gauge to monitor the delivery pressure is also included in the system. The pump is capable of producing pressures high enough to burst the Teflon delivery tubing. The pressure gauge allows the operator to detect abnormally high pressures that occur if the delivery tubing becomes restricted.

Oil is injected onto the Vycor heater very near the monitoring thermocouple and always with the carrier gas flowing. This gas flows

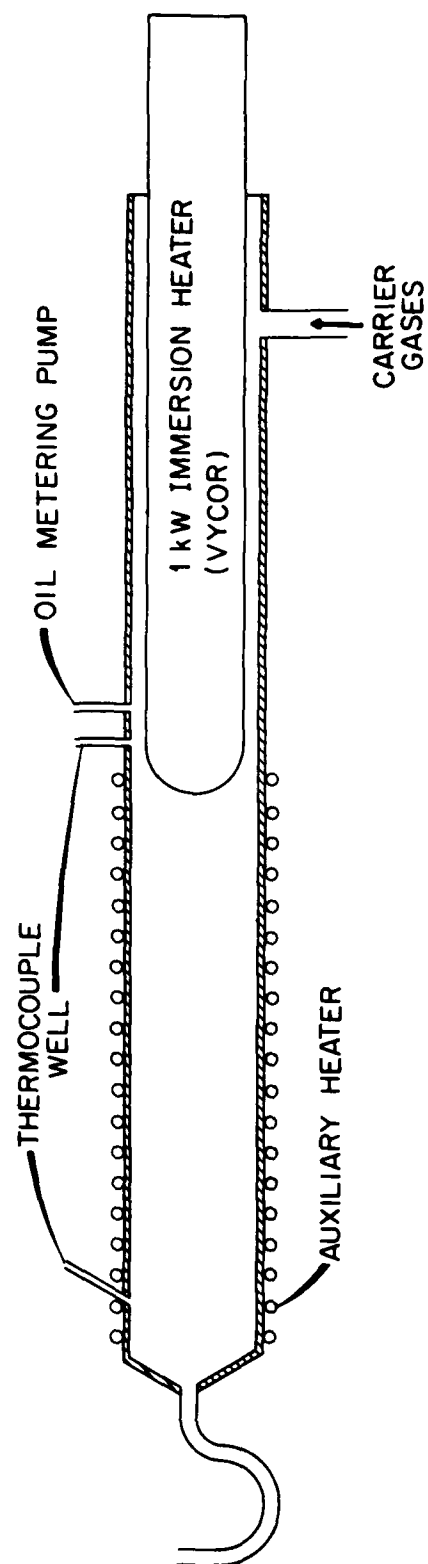


Figure 1. Diesel Fuel Aerosol Generator

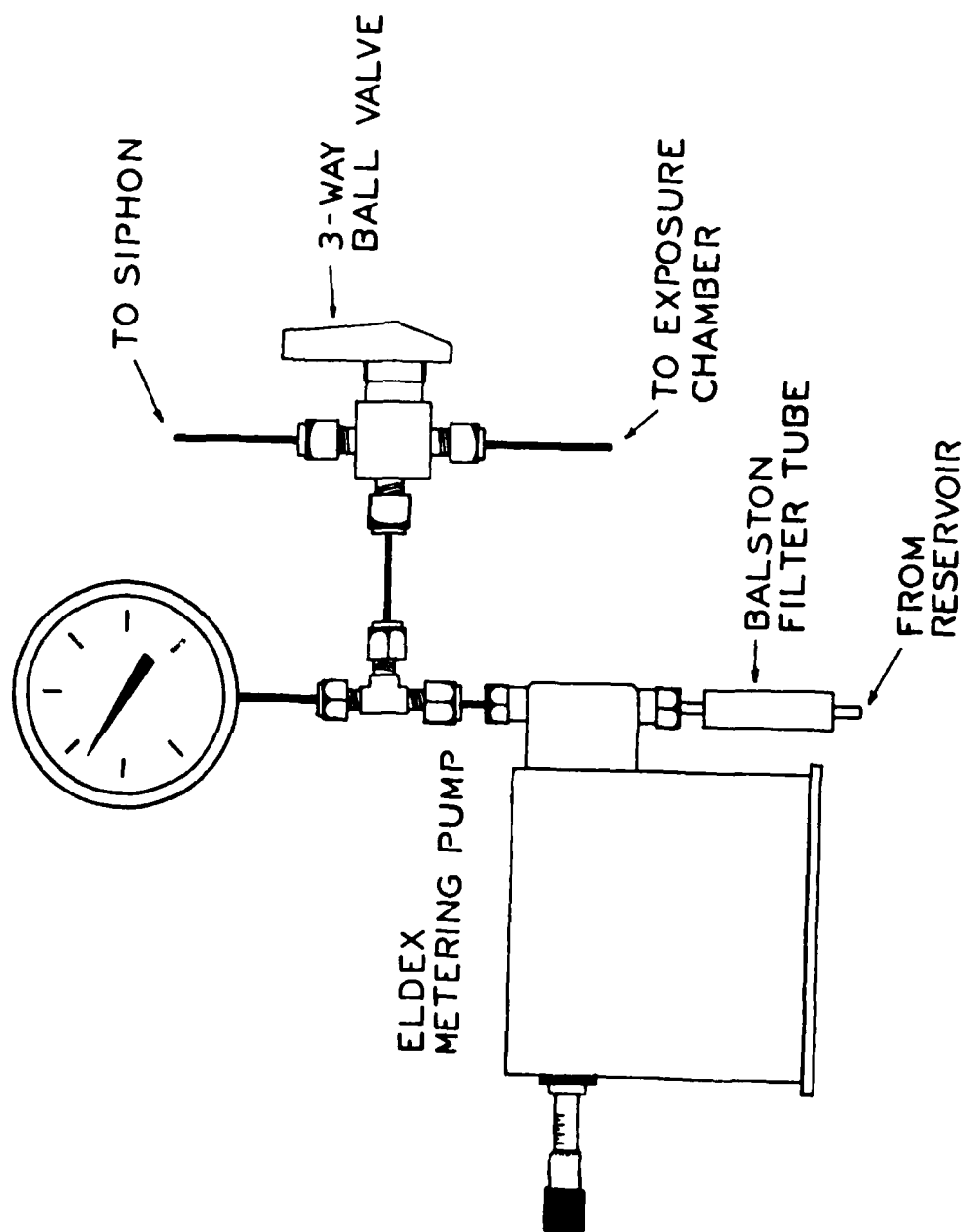


Figure 2. Metering Pump-Diesel Fuel Aerosol Generating System

at 10 liters per minute. For toxicology experiments pure nitrogen is used. It is supplied to all chambers from a regulated liquid nitrogen storage vessel. The gas pressure in the delivery line is monitored. The heaters and the exposure system will shut down if the line pressure is inadequate to supply the requisite nitrogen flow.

#### CHAMBER DESIGN AND MODIFICATION

A schematic diagram of the entire exposure system is shown as Figure 3. Existing chambers of the Rochester type were used. They are square in cross section, with tapered end sections and have a total volume of 1.4 cubic meters. They have a capacity for 45 rat cages hung in five tiers. Conditioned air is fed to the chambers from the top, exhausts at the bottom and is finally filtered through absolute filters provided as a building facility. These chambers are operated with an air throughput of 420 L/min (15 cfm) at a slight negative pressure (1 cm water).

It was found that the existing chamber design was not adequate to distribute the aerosol uniformly throughout the exposure volume. The aerosol stream did not at all disperse in the top section as might be naively expected from the tapered cross section. Rather, it entered as a discrete plume (Figure 4) flowing, with no cages present, directly to the bottom before dispersing. The chamber filled to a steady concentration very slowly and almost exponentially. It should be noted that this phenomenon, easily visualized in our experiments with a highly concentrated aerosol, is probably quite general with chambers of this design. The tapered entry section is of little value in dispersing the aerosol uniformly. This of course posed a serious threat of nonuniform exposures. Not only was the buildup to a uniform concentration slow and uncertain, but, more importantly for this experiment, the aerosol plume would impinge preferentially on the animals in the top center tier of cages.

To correct this problem, an assembly consisting of a dispersing cone and two laminarizing screens (Figure 5) was designed and installed in the upper tapered section of the chamber (see Figure 3). The screens were constructed of 0.080 inch perforated aluminum plate with 10 percent free opening area. Their edges were fitted with neoprene rubber gaskets and they were pressed tightly to the walls of the chamber to prevent preferential flow around their edges. In Figure 5, a gasket has not yet been installed on the upper screen. The cone serves to break up the entering plume and to introduce turbulence above the screens.

With the screens in place, the flow through the chamber was nearly laminar. This is illustrated (Figures 6 and 7) by photographs of the chamber taken shortly after the start of aerosol generation and as the chamber emptied with the generator off. In both cases the front of the advancing or retreating smoke cloud can be clearly seen. The boundary is not discrete as one would expect from perfectly laminar flow.

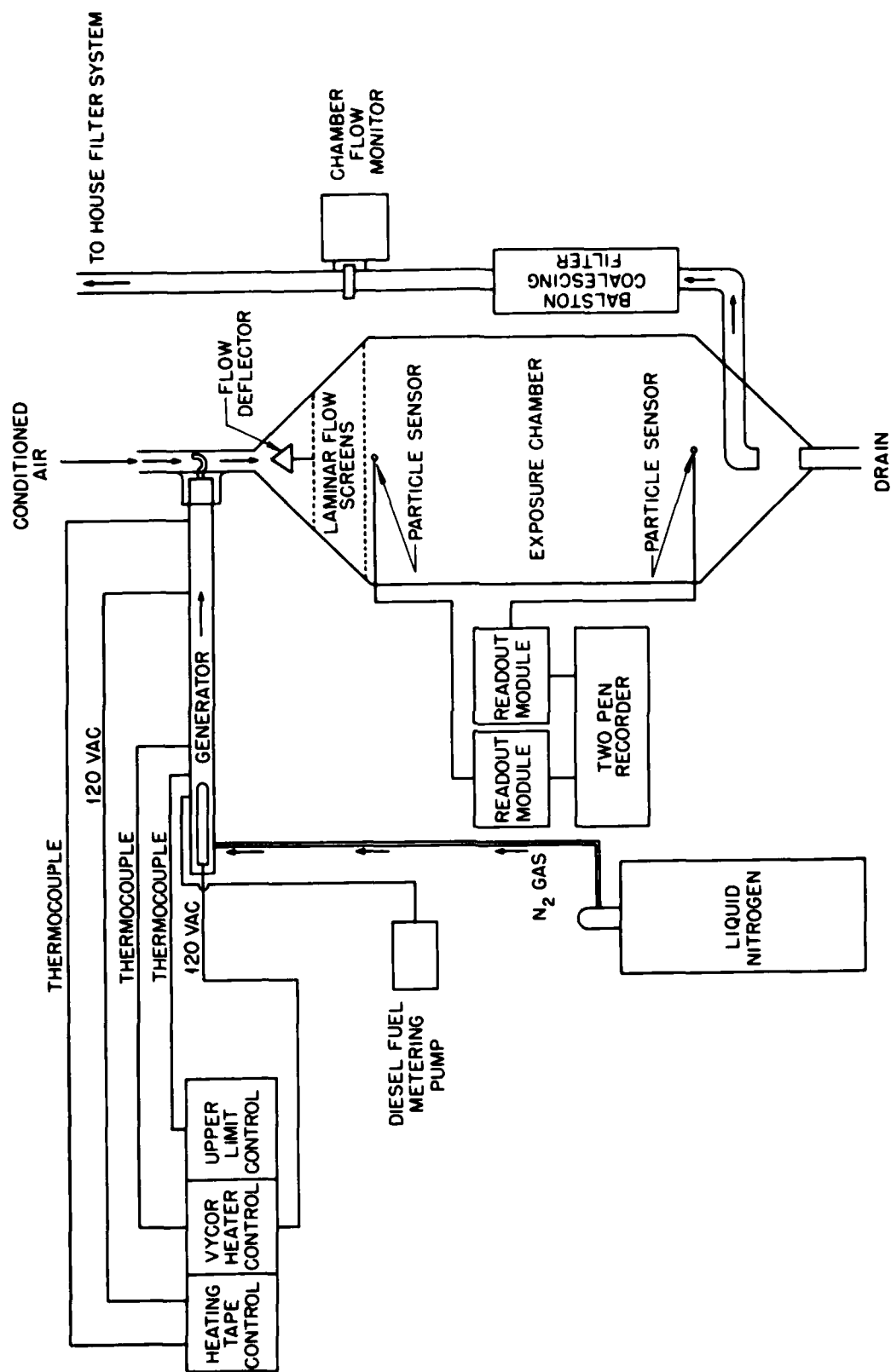


Figure 3. Exposure System Schematic



Figure 4. Diesel Fuel Aerosol Entering Exposure Chamber Without Laminarizing Screens



Figure 5. Laminarizing Screens and Dispersing Cone



Figure 6. Inhalation Chamber Filling with DF2 Aerosol-Laminarizing Screens in Place



Figure 7. Inhalation Chamber Emptying-Laminarizing Screens in Place

Gradients created by the greater density of the aerosol-laden air relative to the air it displaces, contribute to this effect. Note that the boundary is better defined in the case (Figure 7) where the denser aerosol is being displaced by filtered air.

The homogeneity of the aerosol concentration throughout the chamber has also been investigated with ORNL/Gayle particle sensors<sup>(4)</sup>. For this experiment six sensors were calibrated to respond equally to the aerosol concentration and then arrayed in a horizontal plane in the chamber. Their output was fed to a multipoint recorder. In five separate runs the response at each cage level was recorded. The recordings for three of these levels are shown in Figure 8, and the data for all levels are summarized in Table 1. In general, after the aerosol concentration has equilibrated, the spatial and temporal homogeneity exhibits a spread of about 10 percent about the average.

TABLE 1. SPATIAL HOMOGENIETY SUMMARY FOR CHAMBER WITH LAMINARIZING SCREENS<sup>a</sup>

Shelf Number <sup>b</sup>	Median Sensor Response (mv)	Deviation from Median (percent)
2	31	8
3	33	8
4	32.5	11
5	32.5	9
6	33	10

Aerosol concentration 3 mg/L

a. Data taken 24 min. after start of run.

b. Shelf 2 corresponds to top tier of cages.

During these experiments, we observed that even small leaks into the chamber make it difficult to maintain the required homogeneous aerosol. With the chamber operating at slight negative pressures, as is conventional, leaks manifest themselves as jets of incoming air that dilute the aerosol. These jets persist for long distances in the chamber and if unfortunately located can give rise to nonuniform exposures at the site of some of the cages. We suspect that this phenomenon is quite general for chambers operated in this mode, but is not easily detected with low concentration aerosols.

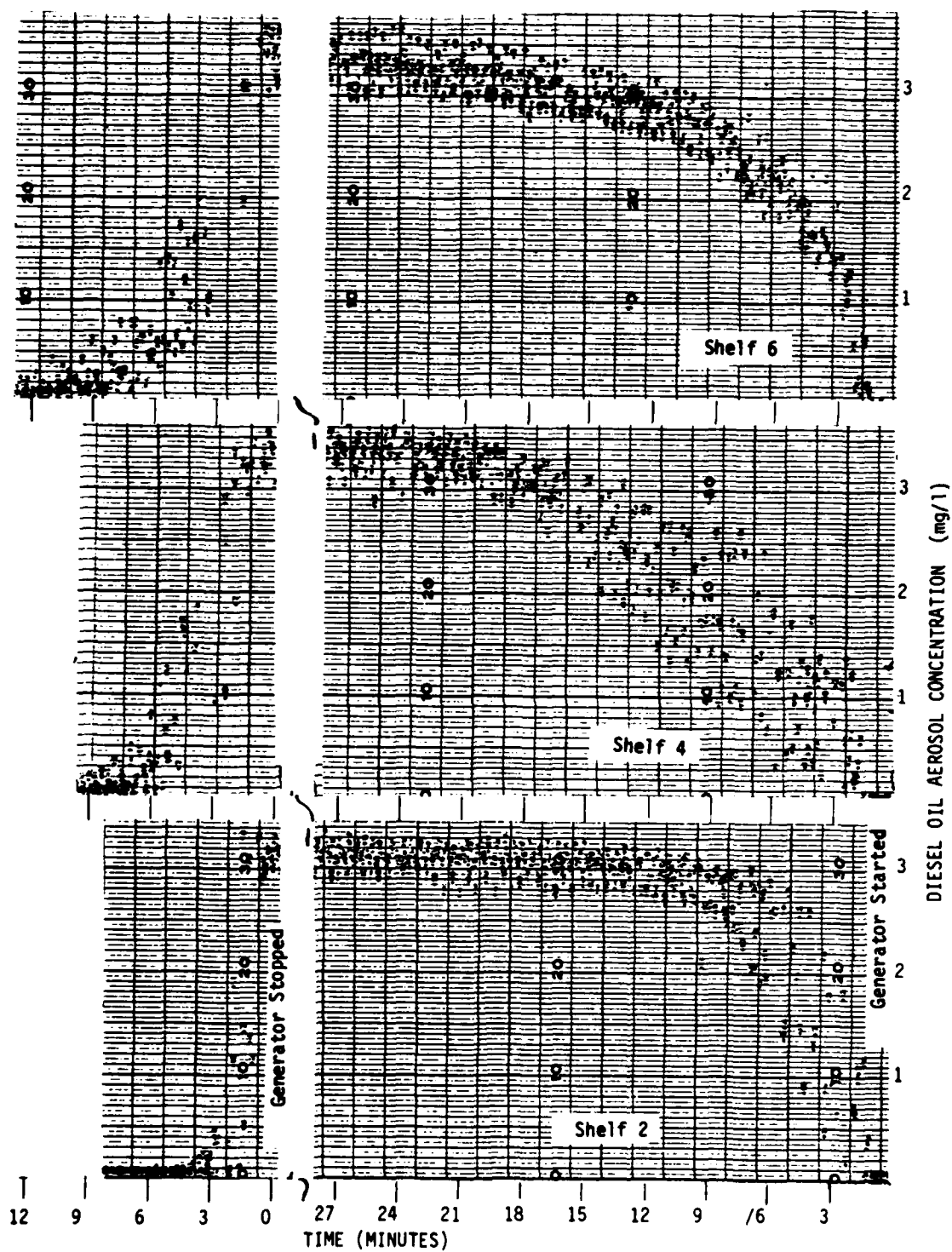


Figure 8. Multisensor Response Showing Homogeneity of DF2 Aerosol

The filling and emptying dynamics of the chamber are important, particularly for short duration exposures. The rate of filling and emptying of these chambers can be illustrated more quantitatively using on-line particle sensors. Two matched sensors were mounted in the chamber, one just above the first tier of cages and one just below the bottom tier. The response is shown in Figure 9. Aerosol concentrations attain 90 percent of steady state in about 10 minutes and, similarly, the chamber empties in about that time.

The exposure facility must accomodate the lengthy exposures to highly concentrated petroleum oil aerosols that will be used in the toxicology studies. The aerosol must be properly disposed of after passing through the chambers. It would be unacceptable to directly vent these fumes into a crowded laboratory environment. Under some exposure conditions, over one liter of liquid oil is consumed in a single chamber in a six hour exposure. The existing facility had only high efficiency filters, designed to remove particulates at concentrations very much lower than would be encountered here. With the concentrated liquid aerosols, these filters plug so rapidly that they could not be used for as long as a single exposure. We have found that tubular coalescing filters are ideally suited for this application. They consist of tubular arrays of thick fibrous filters. The aerosol is injected into the inner annulus where it is removed from the stream, and, in passing through the filter, coalesces to bulk liquid which flows to a reservoir for subsequent disposal. The coalescing filters used in this work were supplied by the Balston Co., Lexington, MA. We have used somewhat oversized arrays of these filters after each chamber to maintain an acceptable pressure drop for the air handling pumps. They remove greater than 99.5% of the aerosol and have required replacement only semianually.

#### MONITORING AND CONTROL

In a toxicology experiment, exposures are made on a routine basis over an extended period of time. In this section we describe the techniques and devices used to control and document the exposure levels and to provide a safety system to prevent accidental overexposures to animals. Again, the emphasis will be on the diesel oil experiments, but because of their physical similarities, our remarks also pertain to Fog Oil exposure systems.

The primary method for measuring aerosol concentrations, particularly at the high concentrations of interest here, is to collect the aerosol on retentive filter pads at a measured flow rate for a given time and determine the weight gained. Cambridge glass fiber filters<sup>(5)</sup> typically 45 mm in diameter are used. These filters are widely used to quantitate and analyze cigarette smoke. They quantitatively remove aerosol particles from the flowing gas stream and, should chemical analyses of the samples be needed, show very low organic impurity backgrounds. Calibrated pumping systems, usually operating at one liter per minute, are used to draw the smoke into the filters.

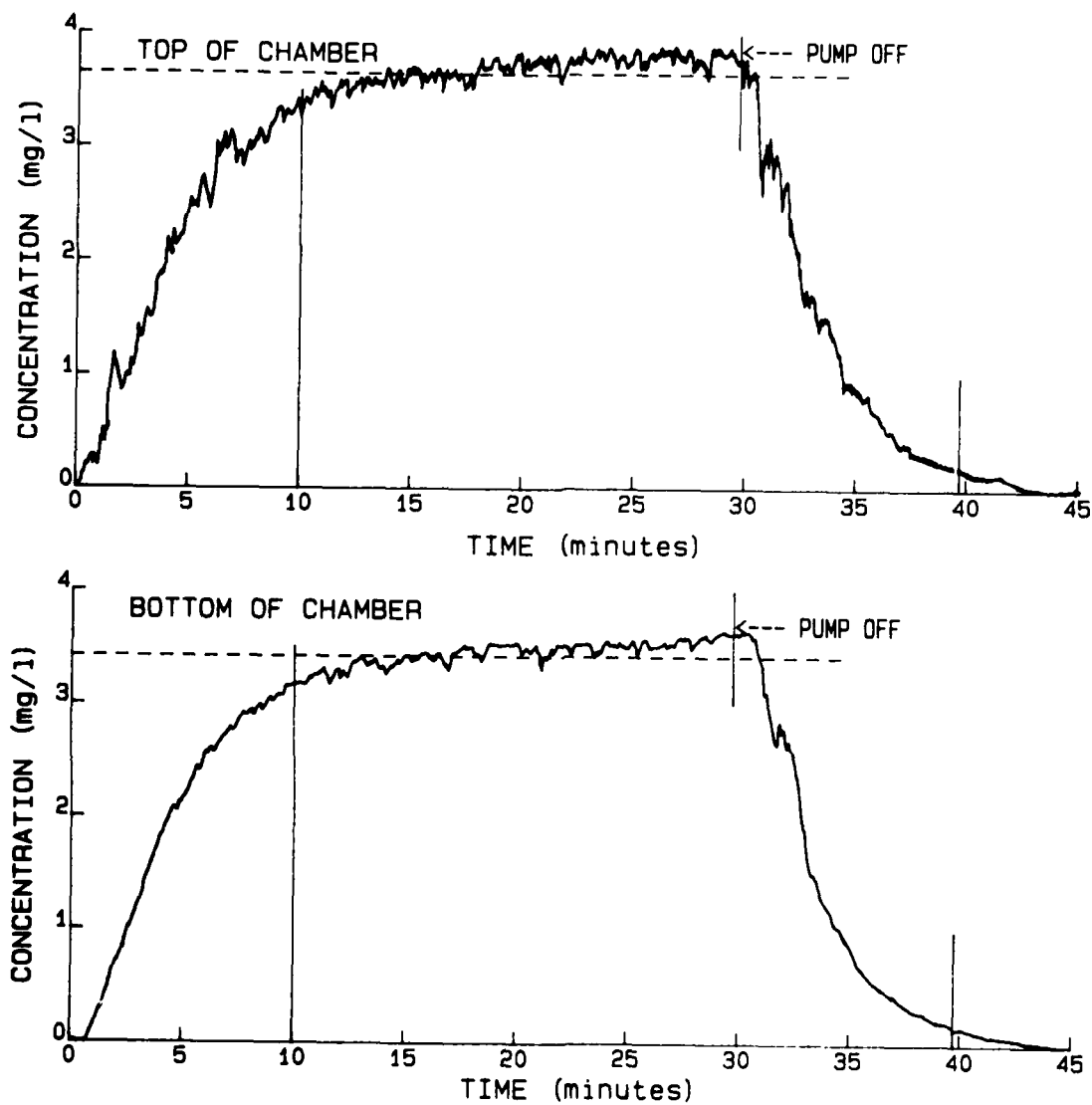


Figure 9. Filling and Emptying Dynamics of Inhalation Chamber

Samples are taken for a sufficient length of time to collect about 50 mg of particulate matter so that weighing errors are minimized.

Gravimetric pad sampling techniques, as described above, are laborious, are subject to errors in a routine environment, and can be used to measure aerosol concentrations only at infrequent intervals. On-line electronic monitoring with ORNL/Gayle particle sensors has been used to monitor the aerosol concentrations in the chambers on a routine basis. The aerosol is monitored routinely at two locations in the exposure chamber: just above the top tier of animal cages and just below the bottom tier. The active element in the sensor is a small solid state light emitting diode-phototransistor combination, 5.5 mm diameter by 4 mm long. It consists of a commercially available light emitting gallium arsenide diode mounted directly beside a high gain phototransistor with an optical separator between the two and a window covering the assembly (TRW/Optron Type OPB-710; TRW/Optron, Carrollton, Texas 75006). Figure 10 is a view of the sensor mounted in the end of a 1/4 inch tube suitable for insertion into a chamber. Figure 11 is a pictorial representation of a sensor with its amplifier-integrator readout module. The module consists of the necessary power supply for the light emitting diode together with amplifier for the phototransistor signal, digital readout of instantaneous concentration, digital display of integrated signal (dose) and a 100 mv (full scale) d.c. output signal for recording and control purposes. The schematic of the amplifier-integrator module is given in Figure 12, while Figure 13 shows a completed unit with a sensor probe. Details of the probe assembly are given in Figure 14.

The phototransistor section of the sensor is responsive to room light, particularly frequencies in the near infrared. Accordingly it is far less responsive to stray fluorescent light than to light from incandescent sources. Small amounts of steady light can be cancelled out by the readout module's "Zero" control. At the aerosol concentrations of interest here (1 to 10 mg/L) steady stray fluorescent light can be tolerated, although it is advisable to shade the chambers to prevent interference from flickering light and moving shadows. The sensor is also an excellent object sensor, requiring the probe to be mounted so that no object is directly in front for a distance of several centimeters.

Each sensor has its own characteristic sensitivity due to manufacturing variations and therefore must be individually calibrated against an actual aerosol. This is done by comparing gravimetric pad samples of the aerosol taken over a known time period with the integrated (or averaged) sensor response provided by the digital integrator on the readout module. The circuitry of the module has adequate adjustment provided (span and gain controls) for standardizing the output over the range of manufacturing variations. In practice, all probe assemblies are calibrated to give approximately 10mv of output for an aerosol concentration of 1 mg/L.

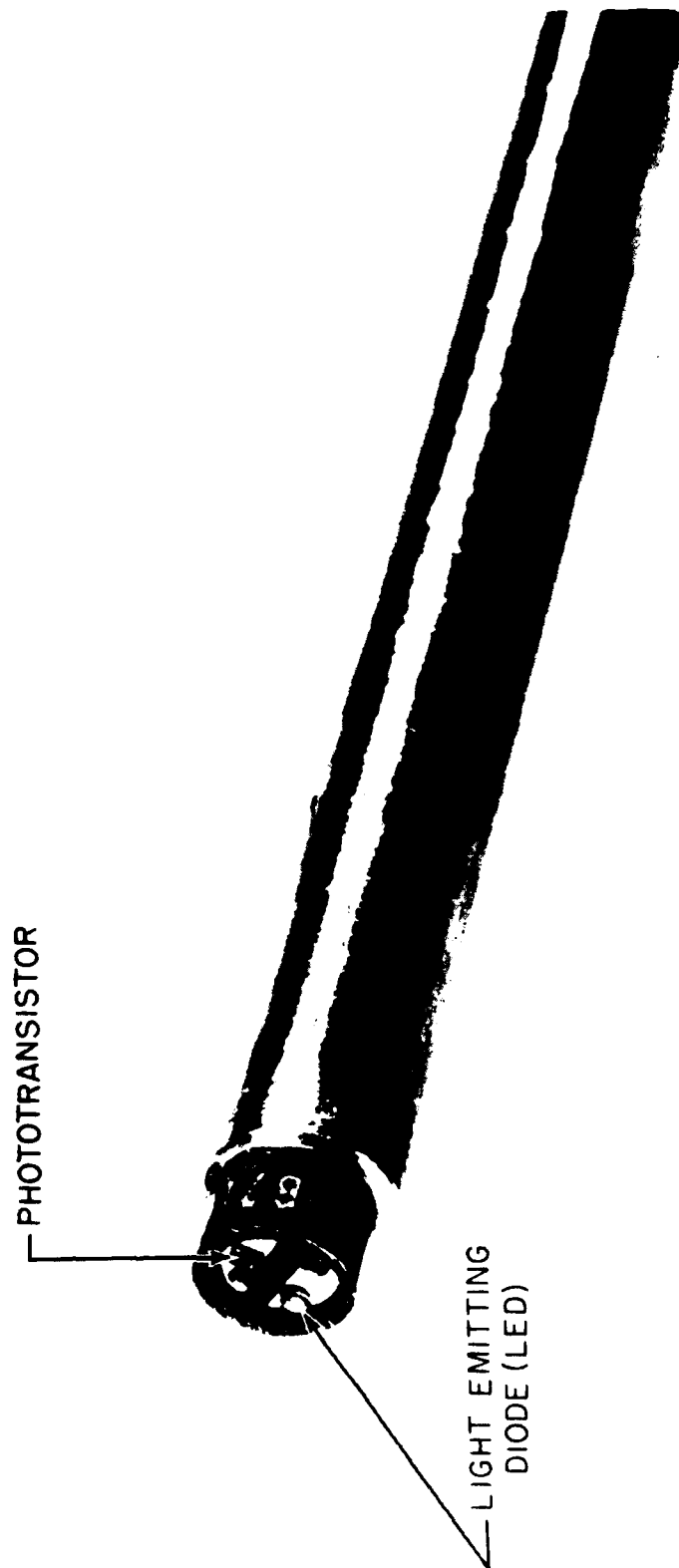


Figure 10. LED-Phototransistor Aerosol Sensor

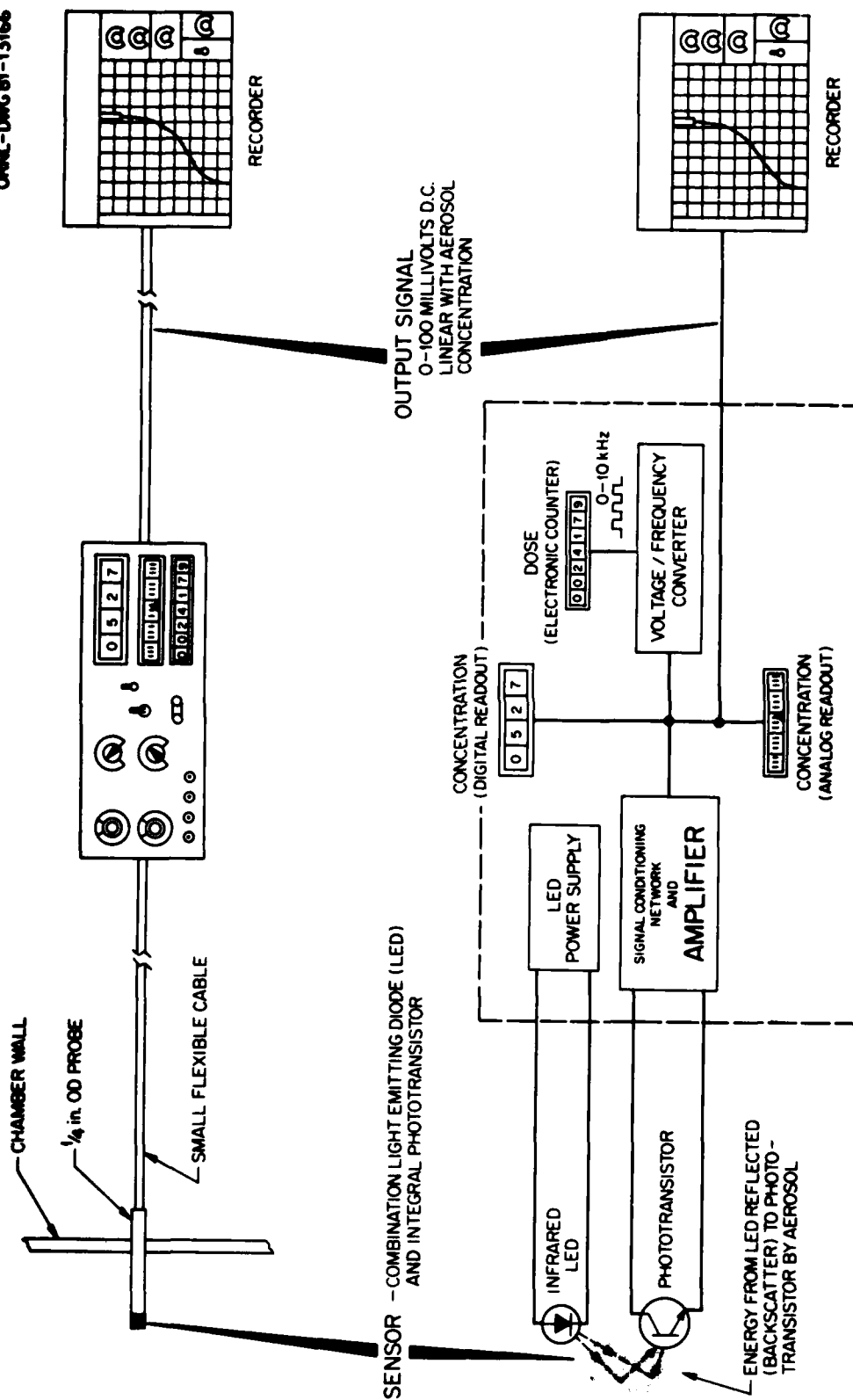


Figure 11. Basic Aerosol Concentration Measuring System



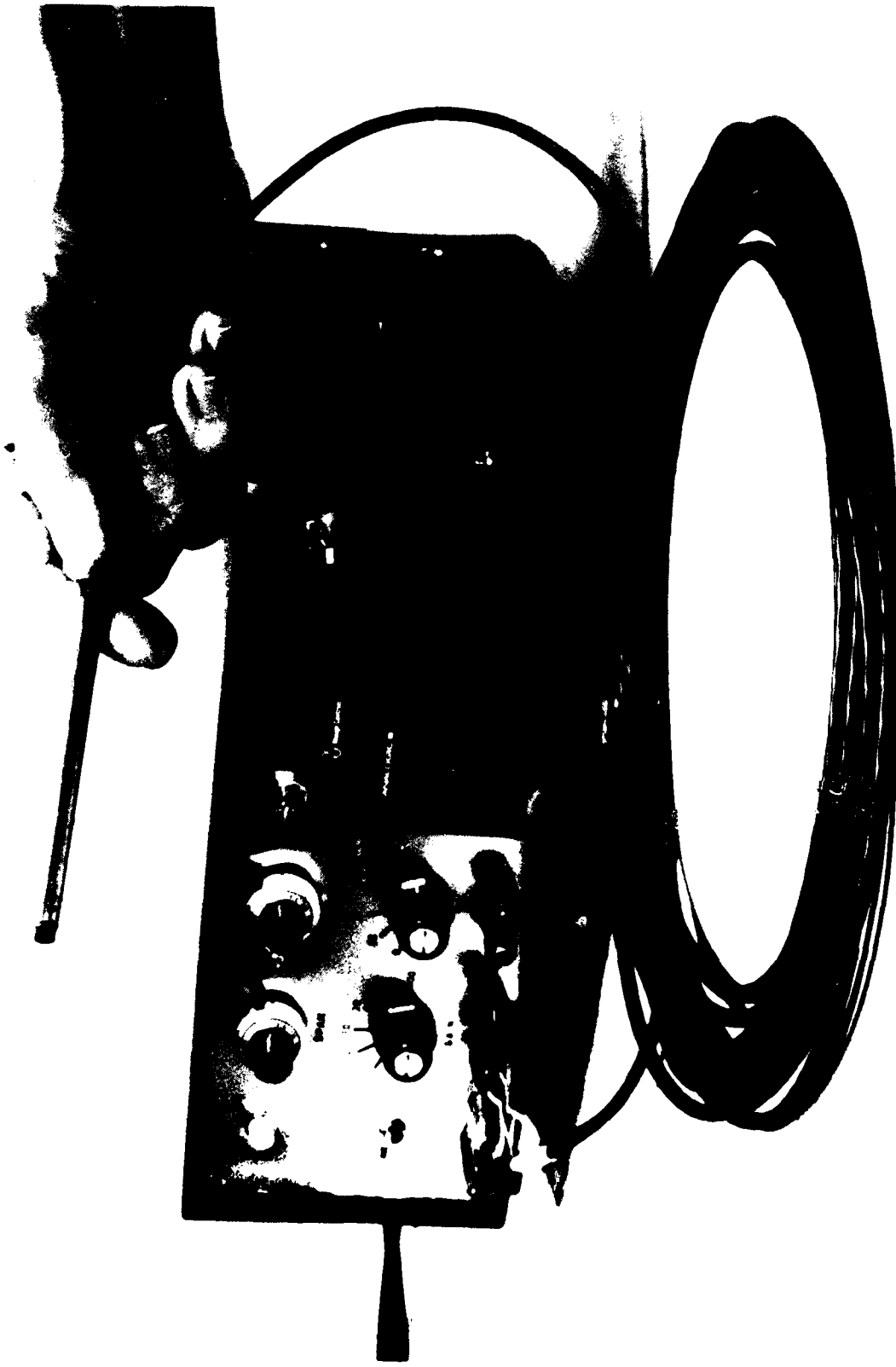
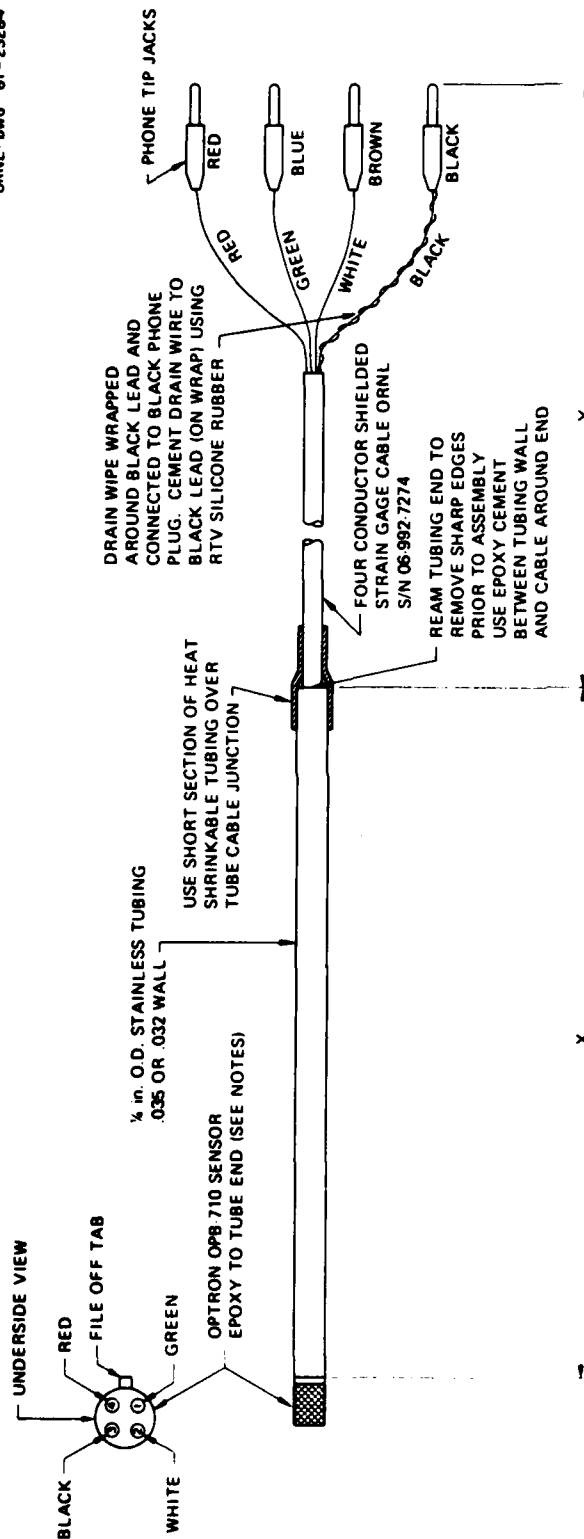


Figure 13. Readout Module with Case and Probe



# NOTES

1. OPTRON OPB 710 SENSOR CASE MUST BE ELECTRICALLY INSULATED FROM METAL TUBE. THIS CAN BE DONE BY PRECOATING SURFACES WITH EPOXY AND LETTING IT HARDEN BEFORE ASSEMBLY OF SENSOR ON TUBE END AND/OR USING A THIN INSULATING FIBER WASHER SANDWICHED BETWEEN SENSOR AND TUBE
2. IN FINAL ATTACHMENT OF SENSOR TO TUBING EXTEND EPOXY DOWN INSIDE TUBING FOR SECURE ATTACHMENT. SENSOR SHOULD BE CENTERED ON TUBE CENTERLINE AS NEAR AS POSSIBLE SO THAT ENTIRE END OF FINISHED ASSEMBLY WILL PASS THROUGH A DRILLED OUT (1/4 in.) SWAGelok TUBE FITTING
3. USE CLEAR EPOXY FOR ALL ASSEMBLY (TRACON 88-2101 OR EQUAL)
4. METAL TUBE SHOULD NOT BE ELECTRICALLY CONNECTED TO CABLE SHIELD OR ANY LEAD
5. X AND Y DIMENSIONS WILL BE SPECIFIED WITH EACH ORDER
6. OPB 710 SENSORS MUST BE SELECTED AND WILL BE SUPPLIED WITH ORDER

Figure 14. Probe Assembly Detail

While the dynamics of optical scattering by aerosol particles are complex, a combination of scattering and absorption effects, transistor characteristics and circuit design are combined to provide a signal that is nearly linear over the aerosol concentration range of interest. Once calibrated, the sensors are remarkably stable in their response with time. Figure 15 shows the response curve of the sensors in an exposure environment. The calibration points were taken, using a single sensor, over a period of six months. In a routine exposure environment, unless great care is taken to eliminate errors in gravimetric pad sampling, we believe that the sensor response is more reliable for estimating aerosol concentration than are pad sampling techniques.

#### TEMPERATURE CONTROL OF AEROSOL GENERATOR

Temperature control of the aerosol generator includes the control of two separate heaters: the Vycor internal rod heater and a tape heater wound on the outside of the generator tube. Chromel-alumel type K thermocouples are used to detect the temperature in the zones appropriate to each of these heaters. Each thermocouple is connected to a Barber-Coleman Model 527Z temperature controller which is capable of modulating up to 20 amperes into the controlled load. These controllers have a digital set-point, analog deviation meter and provide proportional plus automatic reset control action. They also have an adjustable over-temperature alarm which is utilized for automatic shutdown. Figure 16 shows the electrical circuitry of a temperature control network for one generator. A separate temperature limit control (Barber-Coleman Model 121L) has been incorporated into the system to provide a completely independent shutdown circuit operating from its own thermocouple located near the Vycor heater. This was installed to prevent destruction of the generator should the Vycor heater controller fail. (This type of electronic failure is a rare event, but it happened twice in the course of a year and prompted the inclusion of the limit control). If either of the two controllers or the limit control detects a temperature higher than normal, power to the network including the heaters is broken and can be restored only by manual reset after the high temperature conditions clears. As the temperature network shutdown takes place, an extra alarm contact (K2C) actuates a safety control circuit to break power to the oil metering pump to prevent flooding oil into a shutdown generator.

#### SAFETY CONTROL SYSTEM

With several exposure chambers in operation simultaneously and limited personnel, it is not possible to observe each system at all times. It is necessary to provide some measure of protection for the test animals and the exposure system in case of malfunction of any parts of the system. A block diagram of the safety shutdown system designed for the DF2 exposure system is shown in Figure 17. The relay alarm control acts to shut down the oil metering pump and the tempera-

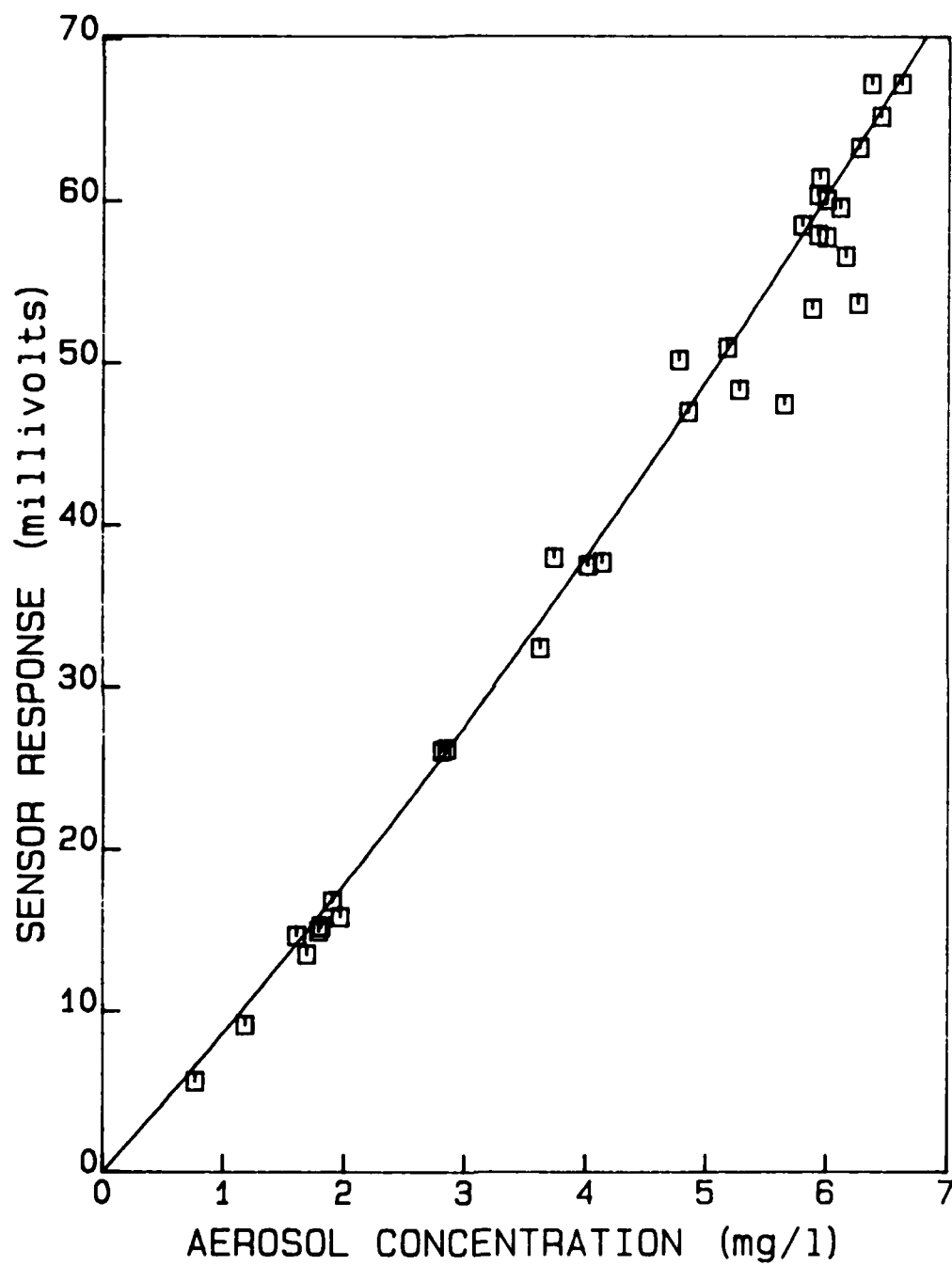
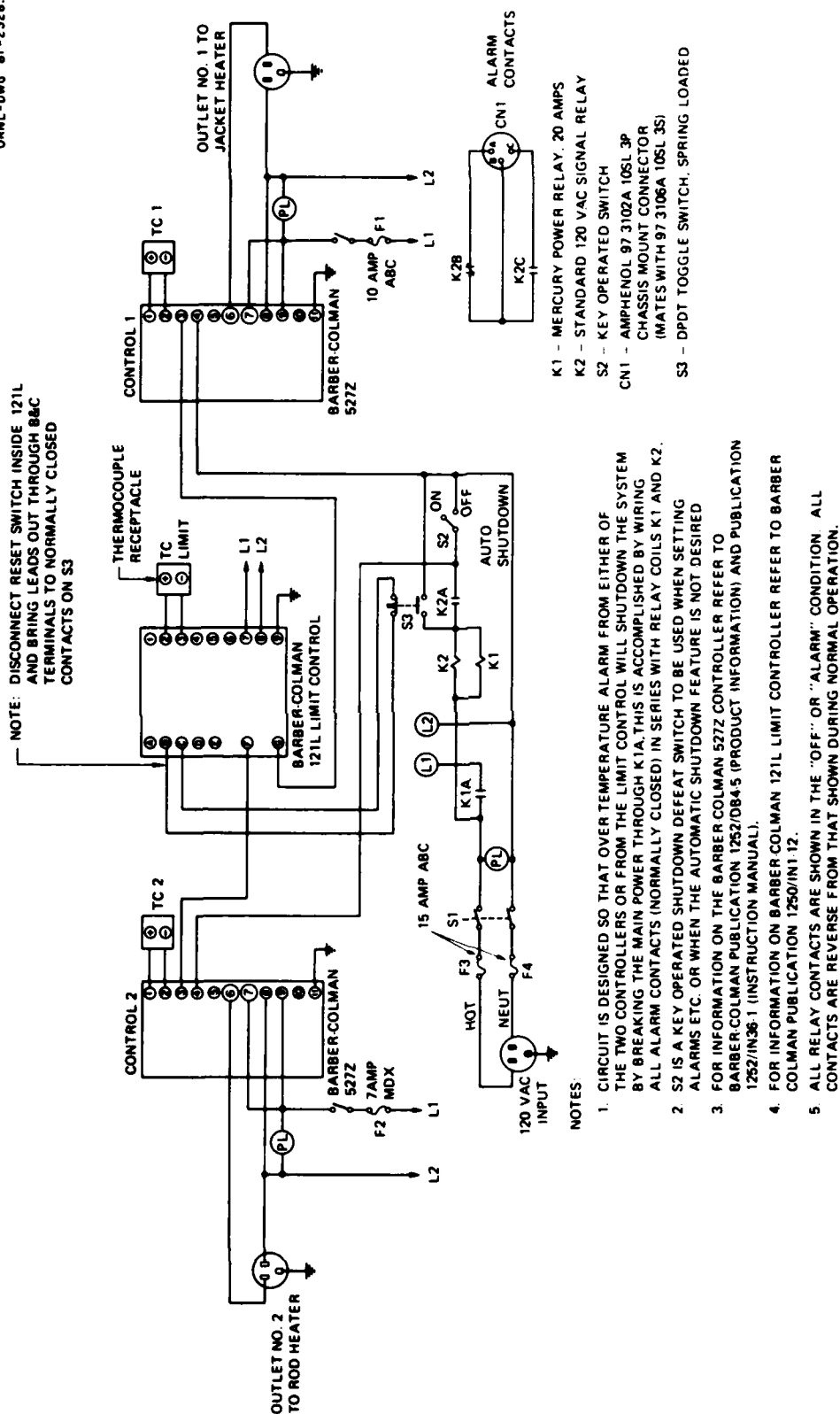


Figure 15. Particle Sensor Response vs. Diesel Oil Aerosol Concentration



- NOTES:
1. CIRCUIT IS DESIGNED SO THAT OVER TEMPERATURE ALARM FROM EITHER OF THE TWO CONTROLLERS OR FROM THE LIMIT CONTROL WILL SHUTDOWN THE SYSTEM BY BREAKING THE MAIN POWER THROUGH K1A. THIS IS ACCOMPLISHED BY WIRING ALL ALARM CONTACTS (NORMALLY CLOSED) IN SERIES WITH RELAY COILS K1 AND K2.
  2. S2 IS A KEY OPERATED SHUTDOWN DEFEAT SWITCH TO BE USED WHEN SETTING ALARMS ETC. OR WHEN THE AUTOMATIC SHUTDOWN FEATURE IS NOT DESIRED.
  3. FOR INFORMATION ON THE BARBER COLMAN 5272 CONTROLLER REFER TO BARBERCOLMAN PUBLICATION 1252/DB45 (PRODUCT INFORMATION) AND PUBLICATION 1252/IN36-1 (INSTRUCTION MANUAL).
  4. FOR INFORMATION ON BARBER COLMAN 121L LIMIT CONTROLLER REFER TO BARBER COLMAN PUBLICATION 1250/IN112.
  5. ALL RELAY CONTACTS ARE SHOWN IN THE "OFF" OR "ALARM" CONDITION. ALL CONTACTS ARE REVERSE FROM THAT SHOWN DURING NORMAL OPERATION.

Figure 16. Temperature Control Network for One Aerosol Generator



ture control network as well as to provide an audible alarm for any of the five signals monitored. Shutdown and alarm are provided in case of (a) nitrogen supply failure to the generator, (b) low chamber air flow through the exposure chamber, (c) open chamber door, (d) high temperature in the aerosol generator, and (e) high aerosol concentration. Each is discussed below.

- (a) Nitrogen supply failure to the aerosol monitor. Nitrogen used as carrier gas for the generator is supplied from a liquid nitrogen tank equipped to deliver the gaseous nitrogen. A backup supply of compressed nitrogen cylinders is on hand. Failure of the nitrogen supply causes a loss in aerosol generation with an accumulation of DF2 in the generator tube. Failure can occur by exhausting the liquid nitrogen supply, failure to switch to the compressed nitrogen cylinders, or failure to open the nitrogen shut off valves in each nitrogen delivery line supplying the individual generators. A pressure switch to signal pressure loss was positioned in the delivery line near the generator and connected to the alarm shutdown system as indicated in Figures 17 and 18.
- (b) Low chamber air flow. Low air flow into the chamber could result in high aerosol concentrations invalidating the exposure, or worse, destroying the test animals. An orifice flowmeter was already located in the air discharge line of each chamber to record the flow rate and signal low flow. The low flow alarm signal from this device was connected to the alarm shutdown system.
- (c) Open chamber door. Start-up of the generator system with the door open or opening the door inadvertently during an exposure will result in escape of the aerosol into the laboratory environment. This could invalidate the exposure and expose laboratory personnel to the test aerosol. An existing switch used to sound an alarm was rerouted to the new alarm shutdown system.
- (d) High temperature in the aerosol chamber. Failure of the temperature control system to the Vycor heater in the generator caused generator meltdown in two instances. To prevent reoccurrence, a separate limit controller was employed in the temperature control network (Figure 16) operated by a separate thermocouple to provide an alarm shutdown independent of the heater controllers.
- (e) High aerosol concentration. Aerosol concentrations above a preselected level would result in an invalid exposure and may result in animal loss. To prevent this occurrence, both of the light scattering monitors (upper and lower) in the exposure chamber were equipped with adjustable alarms activated by aerosol concentrations above the level for which they were

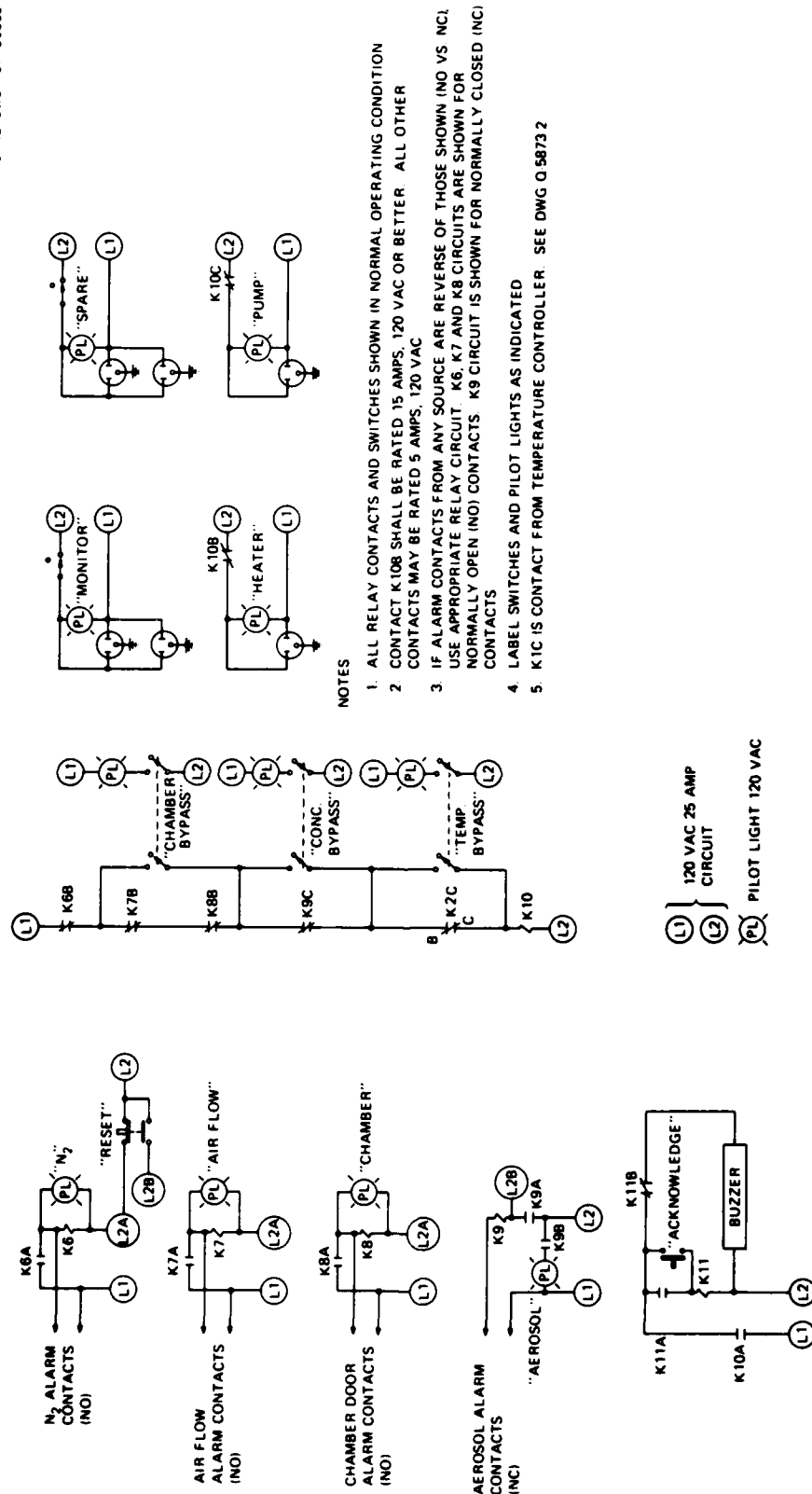


Figure 18. Relay System for Alarm and Shutdown

preset. An out-of-limit concentration at either probe provides for alarm-shutdown of the system.

An electrical schematic detailing the relay system for alarm and shutdown is given in Figure 18. Bypass switches are used around the relay controlling the dropout relay (K10) in order to facilitate start-up. Panel lights are used to inform the operator that these switches are activated and a portion of the safety system is bypassed. An audible buzzer alarm is energized for any fault condition and appropriate "acknowledge" and reset pushbutton switches are incorporated in the circuit.

Testing of the system described was conducted by providing the out of limit condition for each of the five parameters and observing the responses. Interruption of the nitrogen supply, restriction of the chamber air flow, opening the chamber door, exceeding generator temperature, and generating high aerosol concentration were each tested repeatedly to insure that the system performed as designed. The tests were repeated after several weeks of normal operation, with satisfactory results.

#### FOG OIL

The system described above was specifically designed to produce diesel fuel aerosols simulating the processes that occur in the VEES system. Nevertheless, we have found it applicable to other aerosols that can be produced by evaporation-condensation methods. In particular, we have tested it in laboratory chambers (ca. 300L volume) with Fog Oil. Two examples of the particle monitor responses are shown as Figures 19 and 20. In Figure 19, the aerosol concentration was 0.5 mg/L; in Figure 20 it was 5 mg/L. The chamber was operated under the same conditions as in the diesel fuel study: air flow of 200 L/min, and generator temperatures of 600°C and 350°C. In each figure two response curves are shown; the upper curve is for a particle detector mounted near the top (inlet) of the chamber while the lower curve is for one mounted near the bottom. It can be observed that the generators maintained a uniform concentration over the two hour period of the experiments.

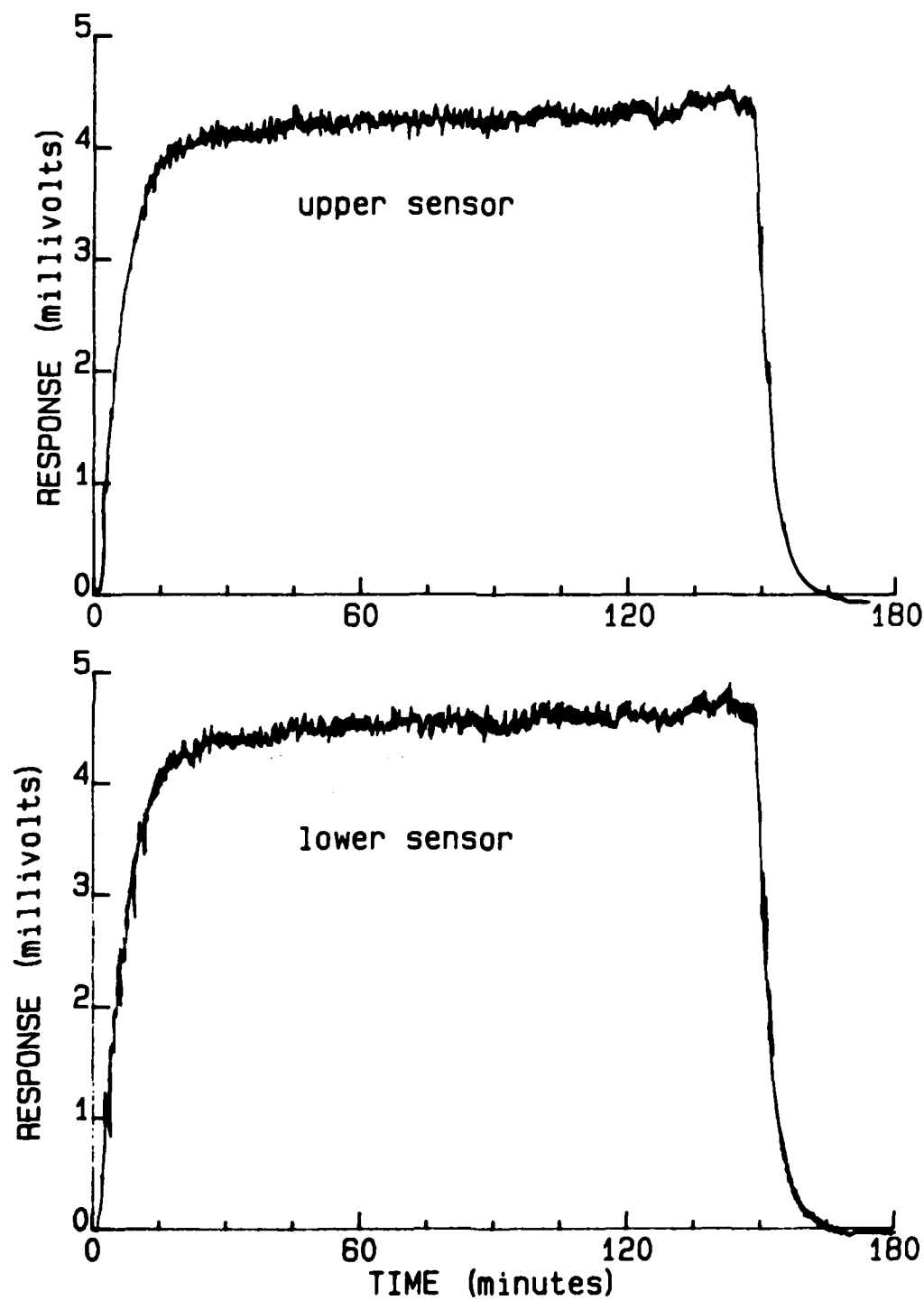


Figure 19. Particle Sensor Responses to Fog Oil Aerosols  
Concentration = 0.5 mg/L

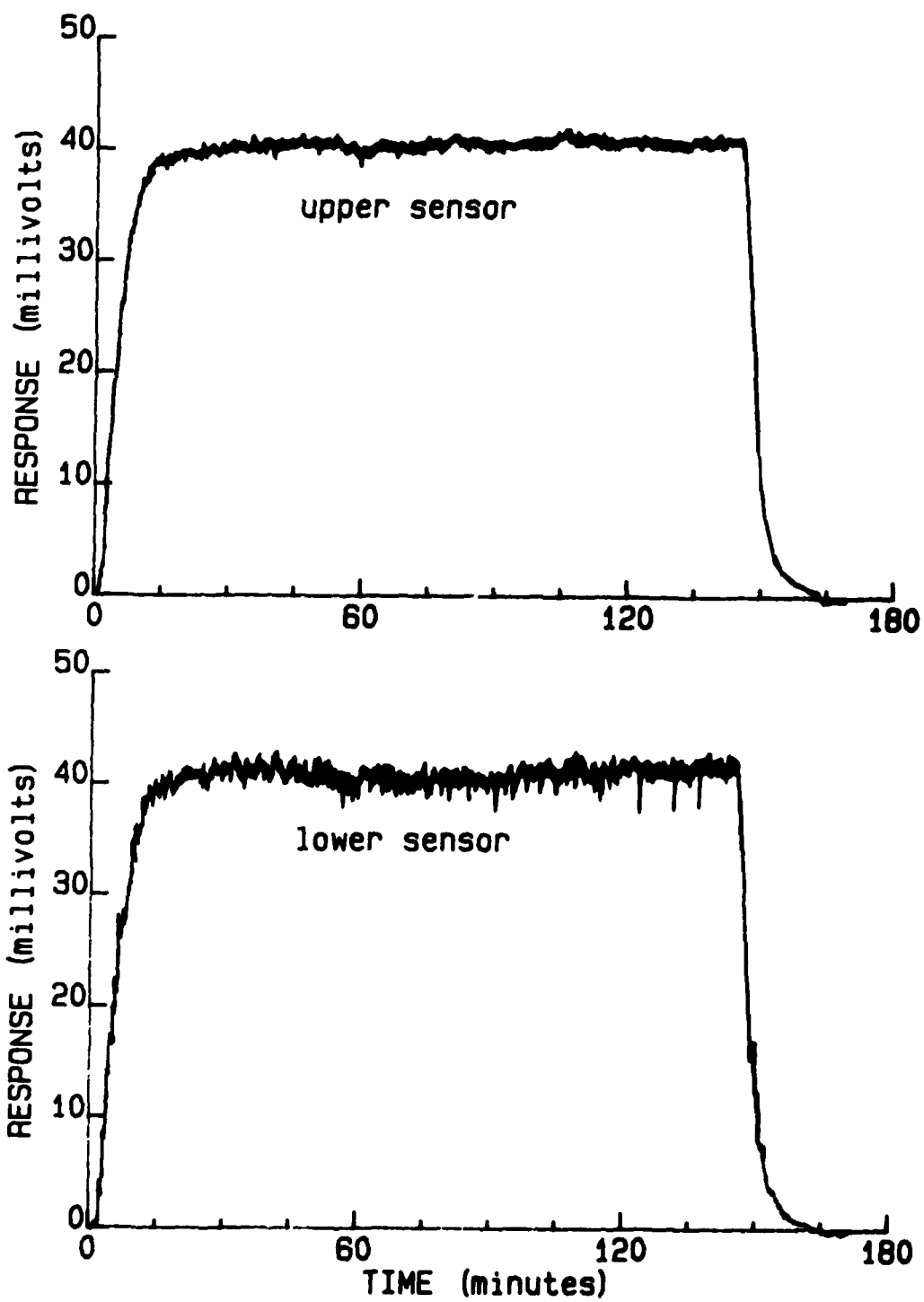


Figure 20. Particle Sensor Responses to Fog Oil Aerosols  
Concentration = 5 mg/L

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# PERSONNEL

The following personnel received support under Army Project Orders 9600, 0027, 1807, 2802 in performance of work described in this report.

M. R. Guerin  
W. E. Dalbey  
R. W. Holmberg  
J. H. Moneyhun  
T. M. Gayle  
P. Berlinski  
M. P. McCann

## PUBLICATIONS

The following publications resulted in whole or in part from the work described in this report.

Holmberg, R. W., J. H. Moneyhun, and W. E. Dalbey. An Exposure System for Toxicological Studies of Concentrated Oil Aerosols. Symposium on Inhalation Toxicology and Technology, Kalamazoo, MI, October 23-24, 1980.

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Dalbey, W. E., S. Lock, R. W. Holmberg, J. H. Moneyhun, and M. R. Guerin. Acute Exposure of Rats to an Inhaled Aerosol of Diesel Fuel. Proc., Smoke/ Obscurants Symposium V, Harry Diamond Laboratories, Adelphi, MD, April 28-30, 1981.

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